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NEAR-FIELD TERAHERTZ TRANSMISSION IMAGING AT 0.210 TERAHERTZ USING A SIMPLE APERTURE TECHNIQUE

Martin S. Heimbeck and Henry O Everitt
Weapons Development and Integration Directorate
Aviation and Missile Research, Development, and Engineering Center

And

Amy E. Frees
Duke University
Durham, NC 27708

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13. ABSTRACT (Maximum 200 Words)

This report discusses a simple aperture useful for terahertz near-field imaging at .2010 terahertz (λ = 1.43 millimeters). The aperture requires no intricate fabrication techniques and connects easily to conventional terahertz output horns. Tests show that the near-field aperture is able to achieve a spatial resolution of $\lambda/7$. The aperture can be scaled with the assistance of machinery found in conventional machine shops to achieve similar results using shorter terahertz wavelengths.

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I. INTRODUCTION

Terahertz radiation has recently gained attention for its usefulness in nondestructive imaging [1]. Terahertz radiation is used to see through nonmetallic objects such as plastic, dry paper, and cloth. [2, 3, 4]. The radiation's unique properties and low photon energy make terahertz imaging a promising alternative to current technologies in security, quality control, and medical diagnostics. However, the long wavelength severely limits the obtainable resolution of traditional diffraction limited terahertz imaging systems [5, 6]. In the case of imaging thin objects in transmission geometries, studies have shown that near-field microscopy can be used to improve the obtainable diffraction limited spatial resolution of terahertz imaging to subwavelength resolution [5]. Terahertz subwavelength imaging was first demonstrated in 1998 when a subwavelength spatial resolution of $\lambda/4$ using a terahertz time-domain system and a conical aperture was achieved [7]. Reference 8 discussed that a spatial resolution of $\lambda/85$ with the use of a complex near-field probe and a terahertz time-domain system was achieved in 2001. Unlike diffraction limited systems which can at best resolve objects on the size of a few wavelengths, near-field imaging resolution is mainly limited by the ability to machine subwavelength apertures that focus and transmit radiation in the form of an evanescent wave efficiently enough to be detected several wavelengths after it passes through the aperture [9]. Applying near-field techniques with terahertz radiation creates the potential for high-resolution, nondestructive imaging of transmissive objects that are several wavelengths thick.

II. THEORY AND EXPERIMENT

By using simple aperture fabrication techniques, the spatial terahertz output can be inexpensively modified from a continuous wave terahertz source to obtain images with subwavelength resolution. In order to quantify the resolution improvements over conventional transmission imaging techniques, compare diffraction-limited and near-field terahertz imaging of a standard 1951 United States Air Force (USAF) resolution target at a terahertz output frequency of 0.210 terahertz.

The resolution limit of diffraction-limited imaging systems is given by the well-known Rayleigh criterion [10]:

$$R = \frac{1}{1.22 * \lambda * f/\#} \tag{1}$$

where, R is the resolution, λ is the wavelength, and $f/\#$ is the object space f-number of the optical system. For this report, radiation at 0.210 terahertz was used, corresponding to a wavelength of 1.40 millimeters. The optical system can be characterized by f/# = 1, meaning that the diffraction-limited Airy disk radius and resolution are 1.71 millimeters and 0.59 millimeters minus 1, respectively. The terahertz source is a solid-state amplifier multiplier chain, which outputs about 2 milliwatts at 0.210 terahertz with a line width on the order or hertz. Its diagonal output horn diameter is approximately 6 millimeters. Figure 1 shows the setup of the diffraction limited system. The terahertz beam is focused onto the USAF resolution target, which is raster-scanned through the focused spot. The detector is located a few millimeters behind the target.

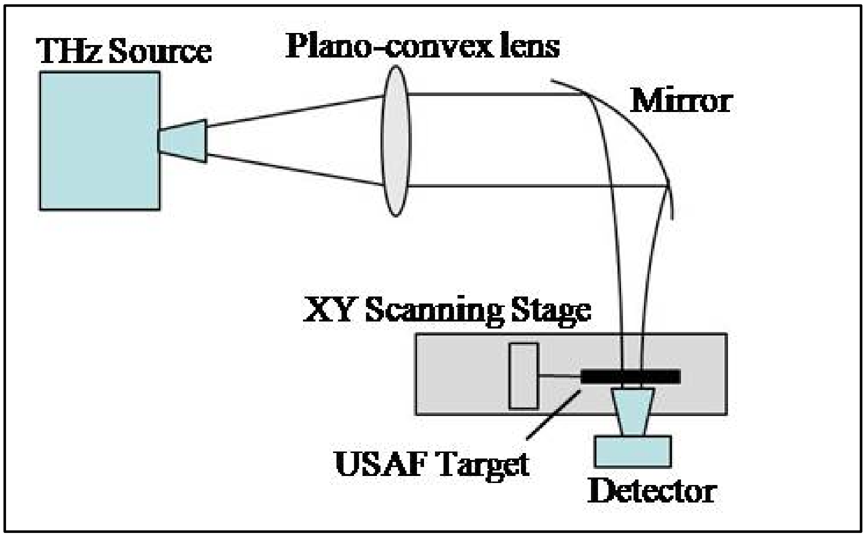

Figure 1. Diffraction Limited Terahertz Imaging Setup

Image resolution can be greatly improved by the use of near-field imaging. The Rayleigh criterion does not apply, and objects separated by less than the system's Airy disk can be distinguished. The system resolution is instead limited by the size of the aperture where radiation is emitted as well as the aperture to object plane separation. The high resolution spot expands approximately as 2π steradians immediately after passing through the aperture. Therefore, in order to be able to take advantage of the high resolution due to the aperture, the sample has to be thin and placed directly in front of the aperture.

For this report, a circular aperture was fabricated with an output diameter of 0.3 millimeters, which was placed in contact with the resolution target. This aperture is an inexpensive, easily reproducible near-field imaging aperture alternative to complex near-field apertures requiring intricate fabrication techniques. The near-field aperture is a conical horn that was rolled up from a sheet of standard aluminum foil. The diameter of the base is approximately 12 millimeters. This allows the conical horn to be directly attached to the source output horn previously described. Figure 2 shows the aperture specifications, and Figure 3 shows the near-field imaging setup.

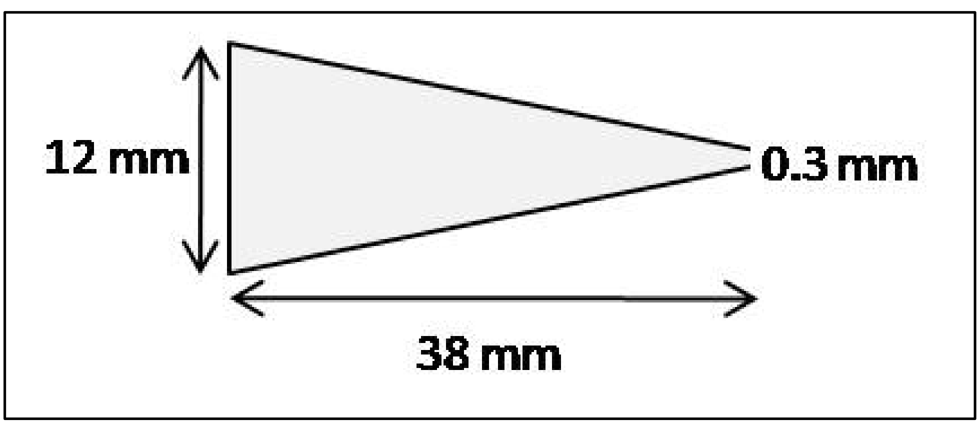

Figure 2. Near-Field Aperture Horn

A 1951 USAF resolution target was imaged using both diffraction-limited and near-field terahertz transmission imaging. The target is a 3-by-3 inch glass plate with a thin coating of chrome. The chrome-coated plate is opaque at 0.210 terahertz, and shows different size line pairs that were edged out of the chrome layer. These line pairs correspond to a variety of spatial resolutions. Figure 4 shows a picture of the 1951 USAF resolution target.

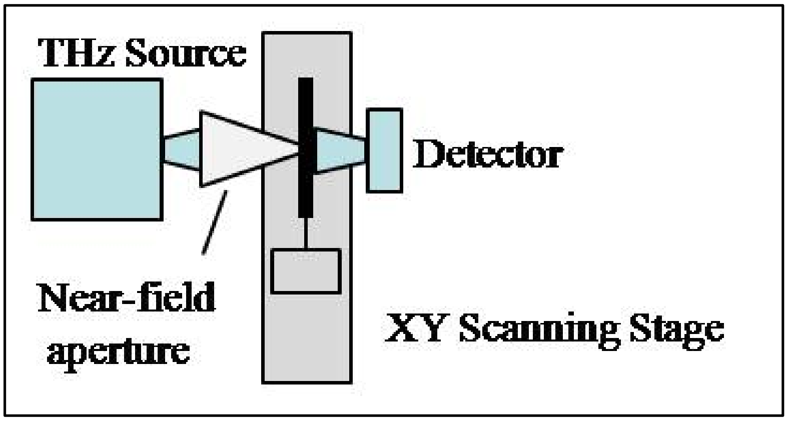

Figure 3. Near-Field Imaging System

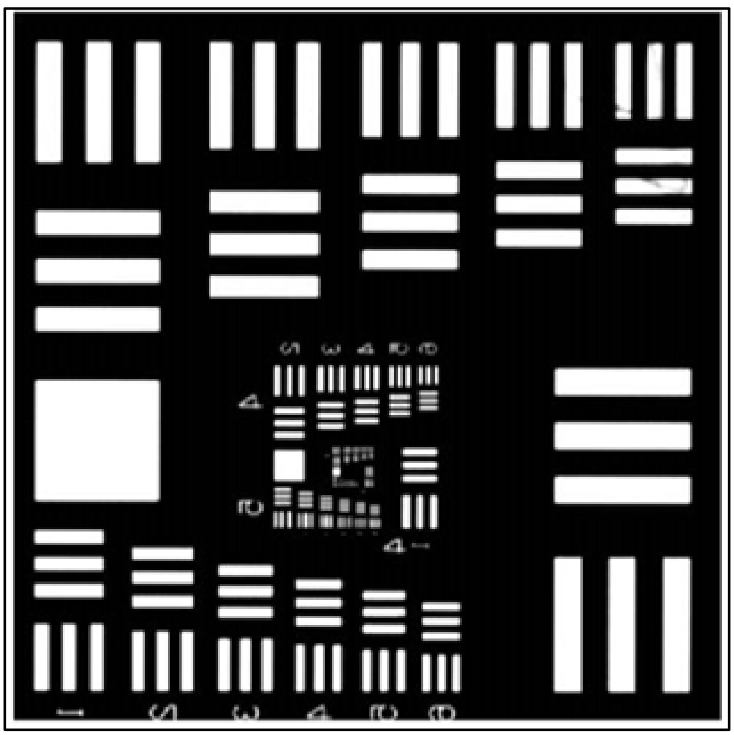

Figure 4. 1951 USAF Resolution Target

III. RESULTS

The system resolution is determined by observing the smallest well-defined set of line pairs. It is important to note that the chrome layer is orders of magnitude thinner than the terahertz wavelength. Furthermore, the tip of the near-field aperture is in contact with the chrome layer. Therefore, assume that the measured resolution is a best-case scenario and that it represents the maximum achievable resolution for the given aperture. For both the diffraction-limited and near-field tests, radiation was maintained at a frequency of 0.210 terahertz. An XY scanning stage was used to raster scan the resolution target laterally across the beam focus or the tip of the aperture.

First, the resolution target was imaged using the diffraction-limited transmission imaging system, as shown in Figure 1. The resulting image is shown in Figure 5. The smallest line set that could be resolved with conventionally focused terahertz radiation at 0.210 terahertz was Element 1 of Group 2. The line set is located inside of the white circle in Figure 5. This line set represents a resolution of 0.250 line pairs/millimeters and corresponds to a resolution of 1 line pair in 4 millimeters, or 1 line in 2 millimeters. Therefore, this imaging setup could, at best, resolve a 2-millimeter object. These experimental data match the previously calculated resolution (Airy disk radius) well. For the near-field imaging experiment, the conical aperture with a circular tip of 0.3 millimeters in diameter was attached to a 0.200- to 0.300-terahertz conical source output horn. The 1951 USAF resolution target was then imaged using the setup shown in Figure 3. Figure 6 shows the terahertz image of the same 1951 USAF resolution target when acquired in the near-field setup.

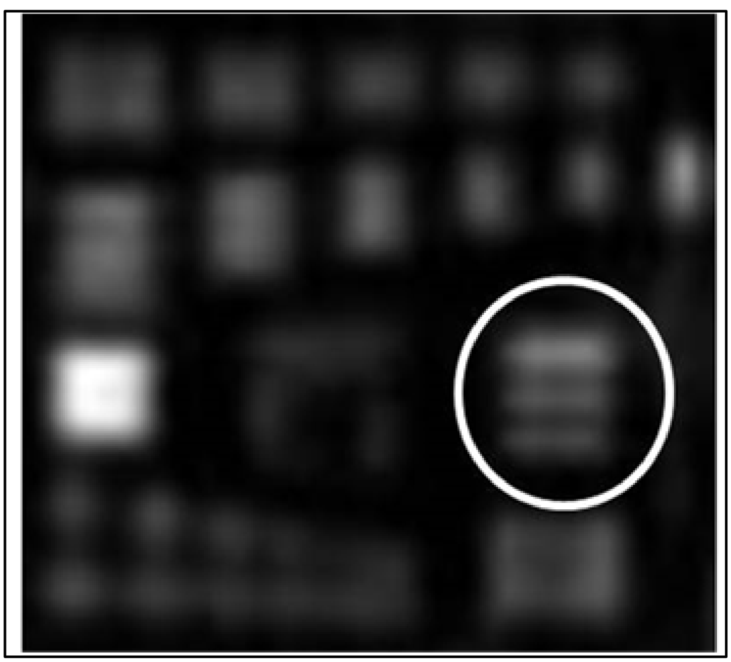

Figure 5. Diffraction Limited Image

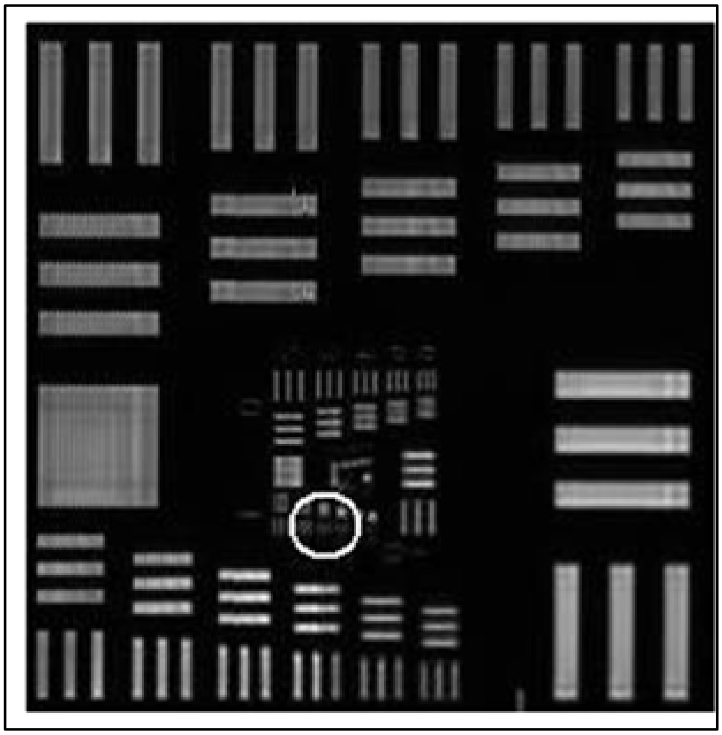

Figure 6. Near-Field Image at 0.210 Terahertz

The smallest line set resolved with near-field imaging was Element 3 of Group 1 and represents a resolution of 2.52 line pairs/millimeters. This corresponds to a resolution of 5 lines/millimeters or a 0.2-millimeter object. The improved resolution is evidenced by the terahertz image in Figure 6. For this report, a resolution of $\lambda/7$ was achieved, compared to diffraction-limited ratio of $\lambda/0.8$. It is interesting to note that the vertical line pairs are better resolved than the horizontal line pairs. This can be explained by a slightly elliptical aperture tip, with is major axis in the horizontal direction and minor axis in the vertical direction. This departure from a perfect circular aperture tip is only apparent for structures that are just resolved. Figure 7 shows three cross sections of the resolution target imaged in the near-field setup.

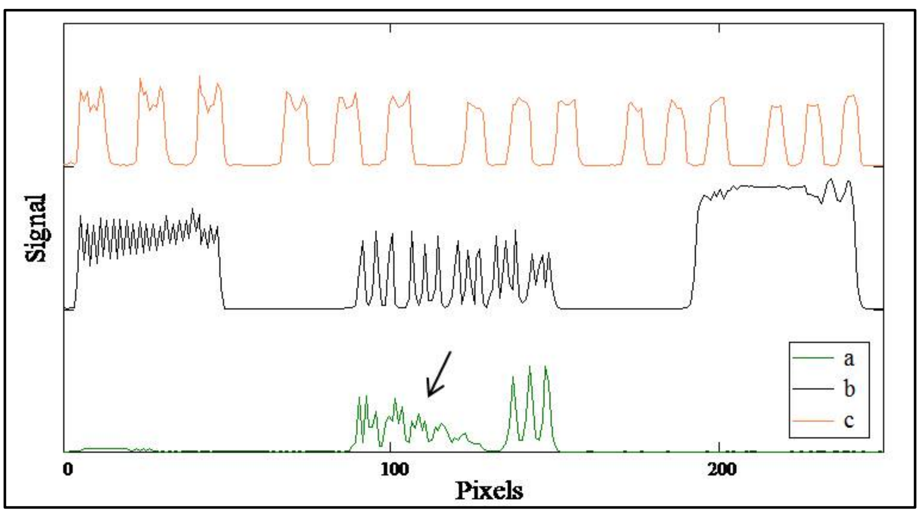

Figure 7. Cross Sections of Near Field Image

The locations of each cross section are indicated in Figure 8. The arrow in Figure 7 identifies Element 3 of Group 1. The three peaks show that the three lines are just resolved. The next smaller pair (Element 4 of Group 1) immediately to the right is no longer resolved.

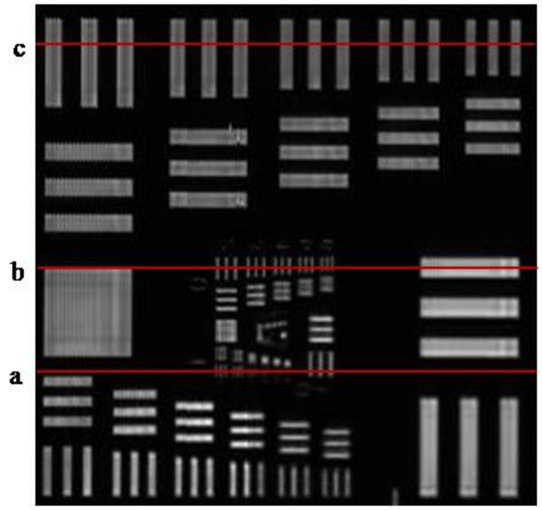

Figure 8. Near-Field Image Showing Locations of Cross Sections in Figure 7

IV. CONCLUSION

Our preliminary test has shown the effectiveness of an easily fabricated aluminum foil aperture in obtaining terahertz images with subwavelength resolution. A resolution of $\lambda/7$ was obtained for a near-field scan at 0.210 terahertz. The method eliminates the need for complex and laborious fabrication techniques while maintaining comparable high resolution quality.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

mm	millimeter
THz	terahertz
USAF	United States Air Force

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